Advanced Lithium Ion Solid Polymer Electrolyte Battery Development

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ABSTRACT

Lockheed Martin Missiles & Space (LMMS), Ultralife Batteries, Inc. (UBI), Eagle Picher Technologies, Inc., Sandia National Laboratories (SNL), and Argonne National Laboratories (ANL) have been developing Lithium Ion Solid Polymer Electrolyte (Li-ion SPE) batteries. Under the National Institute for Standards and Technology's Advanced Technology Program SNL and ANL are developing high energy density anode and cathode active materials, respectively. UBI is incorporating these new materials into optimized Li-ion SPE electrode laminate. Using this new laminate, EPT is developing the cells and batteries for aerospace applications while LMSS has designed and developed advanced battery charge management controller technology.

Introduction

Lockheed Martin Space Systems (LMSS) and Ultralife Batteries, Inc. have been engaged in the development of Lithium Ion Solid Polymer Electrolyte (Li-ion SPE) batteries since 1994. Eagle Picher Industries, LLC. (EPT) has joined this team to help develop and productize Li-ion SPE batteries for the aerospace industry based on Ultralife's technology. This paper describes the status of a Department of Commerce Advanced Technology Program (ATP) project initiated by this team in 1999 to further develop Li-ion SPE batteries for aerospace and consumer electronics applications.

Advanced Technology Program

The goal of the Li-ion SPE Advanced Technology Program is to develop Li-ion SPE batteries with approximately *double* the energy density of existing Li-ion technology. The specific energy and energy density goals are 200-250 Wh/kg and 350-400 Wh/liter, respectively. The cycle life objectives are 2000 cycles at 100% DOD and 35,000 cycles at 25% DOD. The ATP's cycle life goals address the needs of both portable electronics and satellite applications. The target of 35,000 cycles at 25% DOD is based on the requirements for LEO satellites. The cycle life target of 2000 cycles at 100% DOD is derived from portable electronics but is also relevant to GEO satellites which typically require 1000-2000 cycles at 60-80% DOD.

Li-ion cells are emerging for use in portable applications with specific energies in the 150-170 Wh/kg range and energy densities in the 350-400 Wh/l range. Ni/H_2 cells for satellite applications are manufactured in several types of configurations and range in specific energy from 50 to 65 Wh/kg.

ATP Structure

The ATP development strategy is to combine UBI's optimized Li-ion SPE technology with the ultra-high capacity electrode active materials. Concurrently battery designs and charge control electronics will be developed for these new batteries. UBI is responsible for overall cell chemistry, electrode laminate development, and portable electronics cell and battery manufacturing. EPT is responsible for cell and battery development and manufacturing for space applications. LMSS is responsible for charge control management electronics and definition of system requirements for space applications. SNL and ANL are responsible for anode and cathode materials development, respectively.

Materials Development and Cycle Performance

UBI products for portable electronics markets are competitive with liquid lithium-ion systems [1]. These cells use a stacked electrode architecture, $LiCoO_2$ as the cathode active, graphite as the anode active, and fabrication procedures based on Bellcore's plastic lithium-ion (Plion™)

technology [2]. New electrode materials are needed to reach the specific energy targets of this program. Advances on both the anode and cathode side are needed for maximum effect due to cell balancing requirements. SNL is developing advanced carbon composite anode materials. ANL is developing nickel oxide materials. Both SNL and ANL were selected for their extensive experience in battery materials development in these respective areas.

Continuous webs of cathode, anode, and separator are being produced at UBI using production mixing and casting equipment. Central anode bicells have been produced in the range of about 100 mAh to 2.5 Ah using manual and fully automated procedures.

Figure 1 shows typical cycle data for cells using baseline doped nickel oxide material in a cell design used for portable electronic devices. The results are for an unpackaged cell and would be reduced about 5% for a 10 Ah cell packaged in foil laminate material and somewhat more for cells packaged in a metal can. The number of cycles increases as the depth of charge (DOD) decreases as shown in Figure 2.

Cell designs tailored for lower-rate satellite applications use thicker electrodes and higher active loadings in the electrodes. Figure 3 shows capacity versus cycle number for a 2.1 Ah single-plate cell cycling under the simulated low-earth orbit (LEO) protocol below:

- Loop 1
- Charge at 0.4C to 4.0V, then hold at 4.0V until total charge time of 39.14 minutes has elapsed
- Discharge at 0.2C for 36.86 minutes (Discharge 1)
- Discharge at 0.45C for 20 minutes (Discharge 2)
- Repeat Loop 1 seven times (then go to Loop 2)
- Loop 2
- Charge at 0.4C to 4.0V, then hold at 4.0V until total charge time of 53.25 minutes has elapsed
- Discharge at 0.2C for 22.75 minutes (Discharge 3)
- Discharge at 0.45C for 20 minutes (Discharge 4)
- Repeat Loop 2 eight times (then go to Loop 1)

Figure 4 shows the voltage at the end of the various discharge steps as labeled in the protocol above for the same cell shown in Figure 3. Figure 5 shows the end of discharge voltage curves for a 1.5 Ah cell running the same LEO protocol, but designed with thinner electrodes and a lower actives loading content for use in portable electronic devices. Figure 6 shows a 1.5 Ah cell of the same design as that shown in Figure 5 running a geosynchronous earth orbit (GEO) protocol.

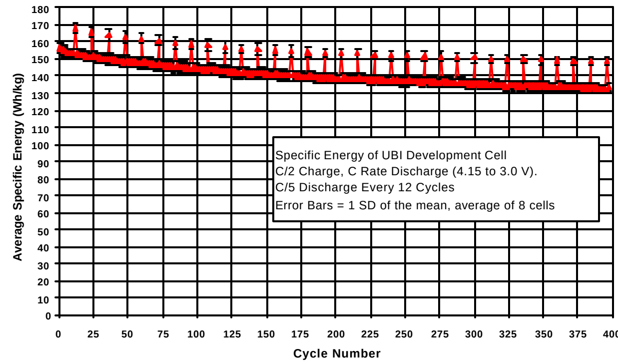

Fig. 1. Cycle life data at ambient temperature for Li-ion SPE Cell

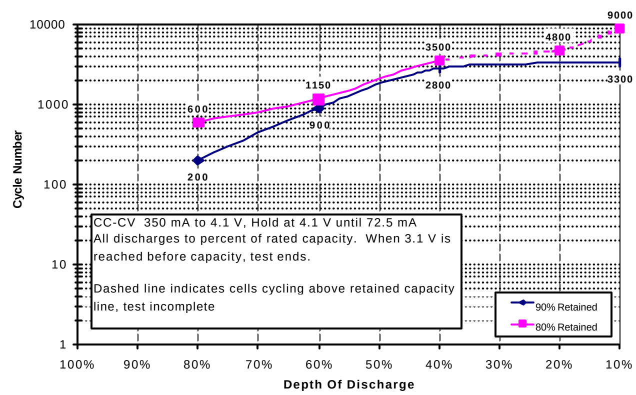

Fig. 2. Cycle number versus DOD and retained capacity. Ambient constant current discharge at 350 ma (C=685 ma). 100% DOD at 350 ma discharge every 100-500 cycles.

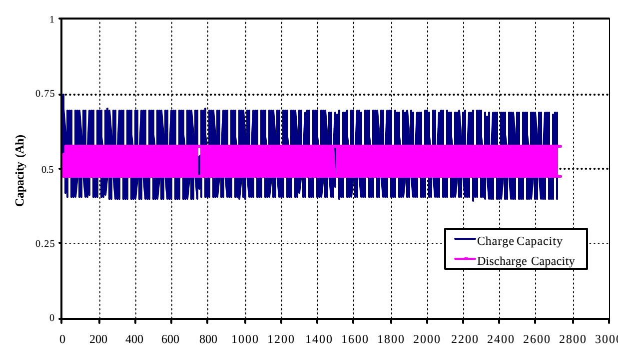

Fig. 3. LEO profile for a 2.1 Ah Li-ion SPE cell designed for use in a satellite. Capacity versus cycle number.

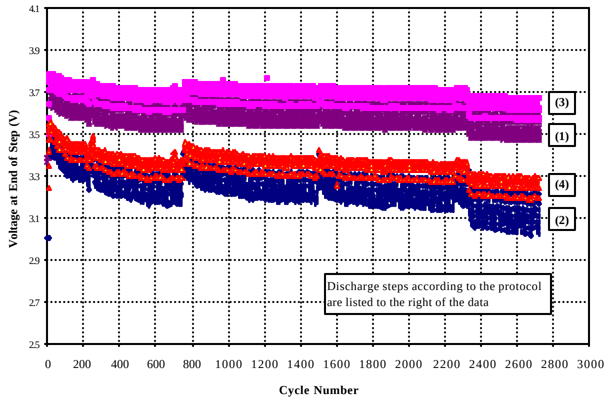

Fig. 4. LEO profile for a 2.1 Ah Li-ion SPE cell designed for use in a satellite. End of discharge voltage at various discharge steps in the cycle protocol. Discontinuities are where the cell was stopped and restarted.

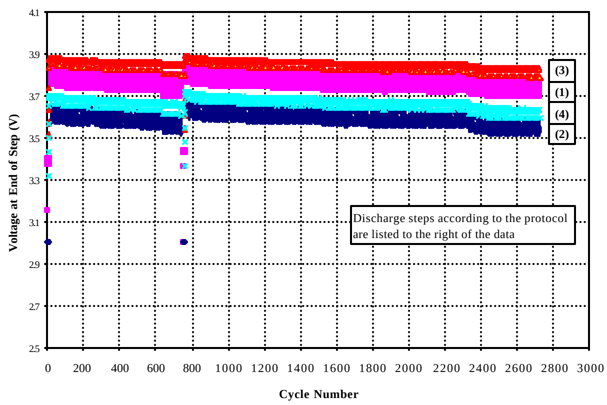

Fig. 5. LEO profile for a 1.5 Ah Li-ion SPE cell designed for use in portable electronic devices. End of discharge voltage at various discharge steps in the cycle protocol. Discontinuities are where the cell was stopped and restarted.

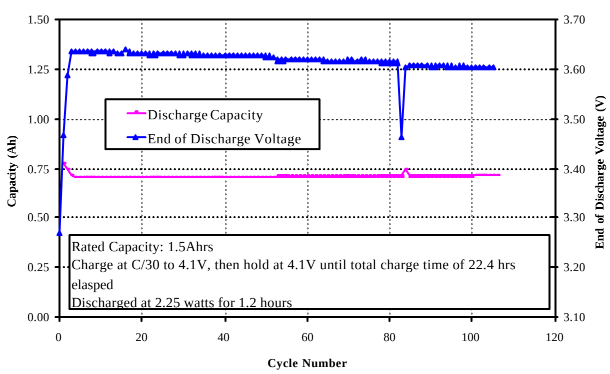

Fig. 6. GEO profile for a 1.5 Ah Li-ion SPE cell designed for use in portable electronic devices. Discharge capacity versus cycle number and end of discharge voltage. DOD is approximately 50%.

Cell and Battery Engineering

Using Li ion polymer laminate developed by UBI, EPT has been assembling and testing 20 Ah cells shown in Fig. 7. Based upon this development a 100 Ah cell design is being established based on GEO telecommunications satellite requirements. They will be incorporated into a prototype battery design, shown in Fig. 8.

Fig. 7. Li Ion Polymer Test Cell

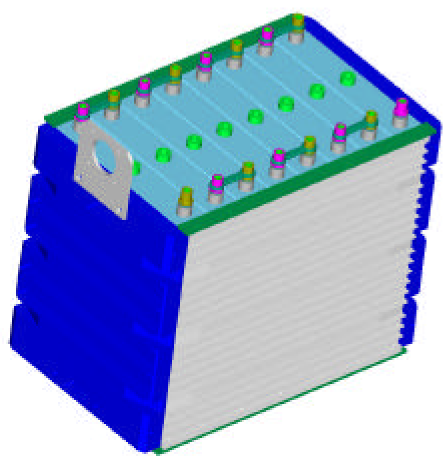

Fig. 8 . Li Ion Polymer Space Battery Design

Battery Charge Management

LMMS has developed several basic strategies for Li-ion battery cell charge balancing [3]. For portable and short duration aerospace applications testing has shown that commercially available charge controlling chips are more than adequate provided the battery package is properly thermally managed so as to prevent diverging impedance growth of initially well balanced cells [4].

For space applications, especially during initial introduction in production systems, multiply redundant cell charge management schemes will be utilized. Charge management circuitry has been designed and tested using discrete surface mounted electronic components on a printed circuit board with a layout as shown in Fig. 9. Multiple boards are needed for each battery and the challenge of this program is to implement the circuits on multi-chip modules and analog/digital ASICs that reduce the packaging requirements for a single system so as to use only a single board.

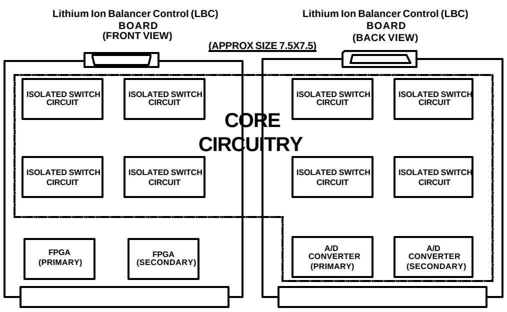

Fig. 9. Battery Management System Charge Control Circuit Topology

SUMMARY

Under a Department of Commerce Advanced Technology Program advanced, ultra-high energy density portable electronic and aerospace batteries are being developed using an advanced Li-ion SPE technology. Materials, laminate, cells and batteries as well as their charge management system in an advanced packaging implementation are the products of this program.

ACKNOWLEDGMENTS

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REFERENCES

[1] Edward A. Cuellar, Michael E. Manna, Ralph D. Wise, Alexei B. Gavrilov, Mathew J. Bastian, Rufus M. Brey, and Jeffrey DeMatteis, J. Power Sources, in press.

[2] A.S. Gozdz, J.-M. Tarascon, P.C. Warren, U.S.Patent 5,460,904.

[3] M. J. Isaacson, R. P. Hollandsworth, P. J. Giampaoli, F. A. Linkowsky, A. Salim, and V. L. Teofilo, Proc. 15thAnnual Battery Conf. On Applications and Advances, p. 193, CSU Long Beach, Jan. 2000.

[4] M. J. Isaacson and V. L. Teofilo, in NASA Space Battery Workshop, Nov. 2000.